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Indications on the Higgs-Boson Mass from the LEP Data

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ABSTRACT

We update our previous analysis on the Higgs mass m_h and the QCD coupling $\alpha_s(=\alpha_s(M_z))$ by using the LEP data after the 1995 Winter Conferences. For $m_t = 180$ GeV we find evidence for a rather large value of the Higgs mass in the range 500-1000 GeV, in agreement with the indications from the W mass.

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Strong evidence for the top quark has been observed by CDF and D0 Collaborations independently [1]. We have now only one yet-undiscovered particle left in the framework of the standard electroweak model. A lot of experimental and theoretical efforts should be made toward this particle, i.e., the Higgs boson. It is not that easy to draw its indirect information from existing experimental data since the Higgs mass m_h enters the one-loop electroweak predictions only logarithmically. Therefore, at present, one can only hope to separate out the heavy Higgs-mass range (say $m_h \sim$ 500-1000 GeV) from the low mass regime $m_h \sim$100 GeV as predicted, for instance, from supersymmetric theories. Such analyses are, however, still very important and indispensable for future experiments at, e.g., LHC/NLC.

In our previous work [2], we have performed a detailed comparison of the LEP data presented at the 1994 Glasgow Conference [3] with the standard model for the various observables. There we obtained some interesting information on m_h and the strong-interaction coupling constant at the Z-mass scale $\alpha_s = \alpha_s(M_z)$. In this note, we shall update this analysis by using the more precise data from the 1995 Winter Conferences as reported by ALEPH, DELPHI, L3 and OPAL in [4] and the new top mass $m_t = 180 \pm 12$ GeV [1].

For our analysis, we used in [2] the disaggregated data, just as presented by the experimental Collaborations, without attempting any average of the various results. This type of analysis is interesting by itself to point out the indications of the various sets of data since even a single measurement, if sufficiently precise, can provide precious information. At the same time, since the LEP data are becoming so precise, before attempting any averaging procedure one should first analyze the various measurements with their errors and check that the distribution of the results fulfills the requirements of gaussian statistics. Without this preliminary analysis one may include uncontrolled systematic effects which can sizeably affect the global averages.

For instance, in [5] a detailed analysis of the relative magnitude of the hadronic

and leptonic widths for the different channels of the various experiments was performed. Starting from the LEP data presented at the Glasgow Conference [3] and using a Monte Carlo method to generate a large number of "a priori" equivalent copies, one finds [5] that the probability of the original LEP population is extremely small (3.8×10^{-4}). Therefore, the meaning of the global average $R = \Gamma_h/\Gamma_l = 20.795 \pm 0.040$ presented in [3] is unclear and substantial systematic effects have to be invoked to understand the distribution of the various measurements.

In the following, we develop analyses similar way to our previous work [2] in order to make the comparison with it easy and convenient. We shall first restrict to a fixed value of the top-quark mass $m_t = 180$ GeV and discuss the indications for the Higgs mass. The experimental data relevant for our analysis are presented in Table I. These are the available, individual results from the various Collaborations as quoted in [4] and the meaning of the various quantities is the same as in [4]. The theoretical predictions in Table II, for several values of α_s and m_h representative of the overall situation, have been obtained with the computer code TOPAZ0 by Montagna et al. [6]. Finally, in Tables III-VI we report the partial and total χ^2 for the various experiments and in Table VII the sum of the χ^2 for the four Collaborations.

Tables I − VII

We find here again some tendencies in the data: The global values of the χ^2 in Table VII confirm that α_s lies at $\sim 3\sigma$ from the DIS prediction $\alpha_s = 0.113 \pm 0.005$ (here, our result is in very good agreement with the general analysis of [7] which gives $\alpha_s = 0.127 \pm 0.005$). Further, by inspection of Table I one finds evidences for some systematic effect in the τ F-B asymmetry. This effect seems to be common to all experiments and it is confirmed by the following remark. Let us consider

the global averages reported in [4]

$$A^o_{FB}(e) = 0.0154 \pm 0.0030, \tag{1}$$

$$A^o_{FB}(\mu) = 0.0160 \pm 0.0017, \tag{2}$$

$$A^o_{FB}(\tau) = 0.0209 \pm 0.0024, \tag{3}$$

and transform the averages for A_e and A_τ [4]

$$A_e = 0.137 \pm 0.009, \quad A_\tau = 0.140 \pm 0.008 \tag{4}$$

into "equivalent" F-B asymmetries by using the standard model formula

$$A^o_{FB}(1) = \frac{3}{4}A_e^2, \quad A^o_{FB}(2) = \frac{3}{4}A_e A_\tau. \tag{5}$$

We find

$$A^o_{FB}(1) = 0.0141 \pm 0.0019, \quad A^o_{FB}(2) = 0.0144 \pm 0.0018 \tag{6}$$

in very good agreement with Eqs.(1,2) but not with Eq.(3). Therefore, there may be some problem in the direct measurement of $A^o_{FB}(\tau)$ since all other measurements are in excellent agreement with each other. Just to have an idea of the effect, if the data for the τ F-B asymmetry are omitted in the evaluation of the χ^2 we find the results illustrated in Table VIII which one should compare with Tables III- VII. The "bulk" of the LEP data, namely those well consistent with each other, show no preference for a light Higgs boson and the best values of the χ^2 are obtained for a large value of m_h, just as in the case of the W mass reported in [8].[♯1]

Table VIII

[♯1] The latest world average of the W-mass is $M_w = 80.27 \pm 0.14$ GeV. Comparing it with the one computed from M_z, we find not only that the central value of m_h must be more than 1 TeV but also that $m_h = 100$ GeV is disfavored (though at 1σ level). See [9] for more details.

Finally, to have an idea of the dependence on m_t, we report in Table IX and Table X the total χ^2 for m_t=170, 180 and 190 GeV including all data or excluding $A^o_{FB}(\tau)$. As first noticed by Ellis et al. [10, 11], by increasing (decreasing) the top-quark mass a larger (smaller) value of m_h is favoured and the shape of the χ^2 is well consistent with all values of the Higgs mass. For $m_t = 180$ GeV, however, Table IX and Table X give rather different information and it becomes crucial to include the more problematic data for $A^o_{FB}(\tau)$ to accommodate values $m_h \sim 100$ GeV.

Tables IX and X

We have of course no mind to say that Tables VIII and X represent a more faithful representation of the real physical situation than Tables VII and IX. Most likely, our results suggest only that further improvement in the data taking is needed for a definitive answer. We may, however, conclude that it is dangerous to focus on a light-mass region in Higgs searches at future experiments. Also, our analysis, confirming the conclusions of [2], shows that the possibility to obtain precious information on the Higgs mass is not unrealistic when the top-quark mass will be measured with a higher precision at the Tevatron.

To better appreciate this point, let us consider the hypothetical situation where m_t would be known to be 180 GeV to very high accuracy (at the end of the century the combined CDF+D0 determination should provide an overall error $\Delta m_t = \pm 3$ GeV [12]). In this case, what would we deduce from the present LEP results? On one hand, we find a clear signal for a heavy Higgs from the very precise data of the OPAL Collaboration (see Table VI) which completely confirms the indications from the W mass. In fact, by inspection of Table VI, the two pairs corresponding to $m_h = 100$ GeV lie outside the 95% C.L. contour ($\Delta\chi^2 = +6.1$) in the two-parameter space (α_s, m_h). This effect is independent on α_s since the pair $(0.13, 100)$ has a total $\chi^2 = 13.87$ with a difference $\Delta\chi^2 = +7$

with respect to the configuration $(0.13, 1000)$ shown in Table VI. On the other hand, in this hypothetical scenario for the top mass, the OPAL trend is not confirmed by the other Collaborations since, by subtracting out the OPAL data from Table VII, ALEPH+DELPHI+L3 give no particular indications. Indeed, their total χ^2 =27.9, 29.1, 28.6 and 31.2, for the four pairs (α_s, m_h) considered in our analysis, produce a maximum difference $\Delta\chi^2 = +3.3$ so that even if the top mass would be known with *infinite* precision to be 180 GeV their data would be well consistent with *all* values of m_h and α_s.

Therefore, *if* we really want to explore the full potentiality of LEP for a precise determination of m_h (and α_s) in the standard electroweak theory, much more stringent tests have to be performed. As stressed in [2], a precise scanning of the Z resonance with 4 or more points at high statistics off peak cannot be postponed anymore ($\sim 90\%$ of the total events have been collected at the pole). Further, a high luminosity phase of LEP I, where each Collaboration will detect millions of Z's per run and the purely statistical errors will become negligible, is needed to obtain a definitive consistency check of the systematics of the various experiments.

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TABLES

	ALEPH	DELPHI	L3	OPAL
$\Gamma_z(MeV)$	2493.2 ± 5.8	2494.1 ± 5.5	2504.0 ± 5.3	2496.0 ± 5.2
σ_{had}(nb)	41.62 ± 0.10	41.27 ± 0.17	41.41 ± 0.11	41.47 ± 0.10
R_e	20.63 ± 0.13	20.86 ± 0.16	20.91 ± 0.12	20.90 ± 0.10
R_μ	20.95 ± 0.12	20.64 ± 0.11	20.85 ± 0.12	20.796 ± 0.073
R_τ	20.68 ± 0.12	20.64 ± 0.16	20.71 ± 0.17	21.00 ± 0.11
$A^o_{FB}(e)$	0.0218 ± 0.0055	0.0221 ± 0.0073	0.0125 ± 0.0070	0.0081 ± 0.0051
$A^o_{FB}(\mu)$	0.0192 ± 0.0039	0.0168 ± 0.0030	0.0164 ± 0.0041	0.0137 ± 0.0027
$A^o_{FB}(\tau)$	0.0217 ± 0.0044	0.0210 ± 0.0057	0.0305 ± 0.0073	0.0183 ± 0.0035
A_e	0.129 ± 0.017	0.136 ± 0.027	0.157 ± 0.021	0.134 ± 0.016
A_τ	0.136 ± 0.015	0.148 ± 0.022	0.150 ± 0.016	0.134 ± 0.013

Table I. The experimental data from the four LEP Collaborations.

α_s	0.113	0.125	0.127	0.130
m_h(GeV)	100	100	500	1000
Γ_z(MeV)	2495.8	2502.3	2498.0	2496.5
σ_{had}(nb)	41.510	41.448	41.439	41.427
R_e	20.703	20.783	20.785	20.795
R_μ	20.703	20.783	20.785	20.795
R_τ	20.750	20.831	20.833	20.843
$A^o_{FB}(e)$	0.0174	0.0174	0.0158	0.0151
$A^o_{FB}(\mu)$	0.0174	0.0174	0.0158	0.0151
$A^o_{FB}(\tau)$	0.0174	0.0174	0.0158	0.0151
A_e	0.1524	0.1524	0.1452	0.1419
A_τ	0.1524	0.1524	0.1452	0.1419

Table II. We report the theoretical predictions at various values of $\alpha_s(M_z)$ and m_h for a fixed top-quark mass $m_t = 180$ GeV. These predictions have been obtained with the computer code TOPAZ0 by G. Montagna, O. Nicrosini, G. Passarino, F. Piccinini and R. Pittau.

ALEPH

α_s	0.113	0.125	0.127	0.130
m_h(GeV)	100	100	500	1000
Γ_z	0.25	2.46	0.68	0.32
σ_{had}	1.21	2.96	3.28	3.72
R_e	0.32	1.38	1.42	1.61
R_μ	4.24	1.94	1.89	1.67
R_τ	0.34	1.58	1.62	1.84
$A^o_{FB}(e)$	0.64	0.64	1.19	1.48
$A^o_{FB}(\mu)$	0.21	0.21	0.76	1.10
$A^o_{FB}(\tau)$	0.96	0.96	1.80	2.25
A_e	1.89	1.89	0.91	0.58
A_τ	1.20	1.20	0.38	0.15
TOTAL χ^2	11.2	15.2	13.9	14.7

Table III. Individual and total χ^2 from the ALEPH Collaboration at various values of $\alpha_s(M_z)$ and m_h for m_t =180 GeV.

DELPHI

α_s	0.113	0.125	0.127	0.130
m_h(GeV)	100	100	500	1000
Γ_z	0.10	2.22	0.50	0.19
σ_{had}	1.99	1.10	0.99	0.85
R_e	0.96	0.23	0.22	0.16
R_μ	0.33	1.69	1.74	1.99
R_τ	0.47	1.42	1.45	1.61
$A^o_{FB}(e)$	0.41	0.41	0.74	0.92
$A^o_{FB}(\mu)$	0.04	0.04	0.11	0.32
$A^o_{FB}(\tau)$	0.40	0.40	0.83	1.07
A_e	0.37	0.37	0.12	0.05
A_τ	0.04	0.04	0.02	0.08
TOTAL χ^2	5.1	7.9	6.7	7.2

Table IV. The same as in Table III for the DELPHI Collaboration.

L3

α_s	0.113	0.125	0.127	0.130
m_h(GeV)	100	100	500	1000
Γ_z	2.39	0.10	1.28	2.00
σ_{had}	0.83	0.12	0.07	0.02
R_e	2.98	1.12	1.09	0.92
R_μ	1.50	0.31	0.29	0.21
R_τ	0.06	0.51	0.52	0.61
$A^o_{FB}(e)$	0.49	0.49	0.22	0.14
$A^o_{FB}(\mu)$	0.06	0.06	0.02	0.10
$A^o_{FB}(\tau)$	3.22	3.22	4.05	4.45
A_e	0.05	0.05	0.32	0.52
A_τ	0.02	0.02	0.09	0.26
TOTAL χ^2	11.6	6.0	8.0	9.2

Table V. The same as in Table III for the L3 Collaboration.

OPAL

α_s	0.113	0.125	0.127	0.130
m_h(GeV)	100	100	500	1000
Γ_z	0.00	1.47	0.15	0.01
σ_{had}	0.16	0.05	0.10	0.18
R_e	3.88	1.37	1.32	1.10
R_μ	1.62	0.03	0.02	0.00
R_τ	5.17	2.36	2.30	2.04
$A^o_{FB}(e)$	3.32	3.32	2.28	1.88
$A^o_{FB}(\mu)$	1.88	1.88	0.60	0.27
$A^o_{FB}(\tau)$	0.07	0.07	0.51	0.84
A_e	1.32	1.32	0.49	0.24
A_τ	2.00	2.00	0.74	0.37
TOTAL χ^2	19.4	13.9	8.5	6.9

Table VI. The same as in Table III for the OPAL Collaboration.

ALEPH+DELPHI+L3+OPAL

α_s	0.113	0.125	0.127	0.130
m_h(GeV)	100	100	500	1000
TOTAL χ^2	47.3	43.0	37.1	38.1

Table VII. Total χ^2 for the four Collaborations.

α_s	0.113	0.125	0.127	0.130
m_h(GeV)	100	100	500	1000
ALEPH	10.2	14.3	12.1	12.5
DELPHI	4.7	7.5	5.9	6.2
L3	8.4	2.8	3.9	4.8
OPAL	19.4	13.8	8.0	6.1
TOTAL χ^2	42.7	38.4	29.9	29.6

Table VIII. Total χ^2 for the four Collaborations by excluding the data for $A^o_{FB}(\tau)$.

ALEPH+DELPHI+L3+OPAL

α_s	0.113	0.125	0.127	0.130
m_h(GeV)	100	100	500	1000
m_t(GeV)$=170$	46.3	38.4	38.3	41.2
$=180$	47.3	43.0	37.1	38.1
$=190$	51.8	50.4	38.9	37.5

Table IX. Total χ^2 for the four Collaborations at various values of m_t.

ALEPH+DELPHI+L3+OPAL

α_s	0.113	0.125	0.127	0.130
m_h(GeV)	100	100	500	1000
m_t(GeV)$=170$	40.7	32.8	29.7	31.2
$=180$	42.7	38.4	29.9	29.6
$=190$	50.1	46.6	32.9	30.3

Table X. Total χ^2 for the four Collaborations at various values of m_t by excluding the data for $A^o_{FB}(\tau)$.